Magnetic Shielding for nnbar

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Magnetic shielding for the ILL experiment
Experimental verification of the internal field using polarized neutrons
Multilayer shield options
Issues for magnetic shielding for vertical experiment/UCN experiment
R&D questions

Neutron-Antineutron Oscillations: Formalism

$\alpha \neq 0$ allows oscillations

$$\Psi = \begin{pmatrix} n \\ \bar{n} \end{pmatrix}$$ n-nbar state vector

$$\mathrm{H} = \begin{pmatrix} E_n & \alpha \\ \alpha & E_{\bar{n}} \end{pmatrix}$$ Hamiltonian of n-nbar system

$$E_n = m_n + \frac{p^2}{2m_n} + U_n \quad ; \quad E_{\bar{n}} = m_{\bar{n}} + \frac{p^2}{2m_{\bar{n}}} + U_{\bar{n}}$$

Note :

- α real (assuming T)
- $m_n = m_{\bar{n}}$ (assuming CPT)
- $U_n \neq U_{\bar{n}}$ in matter and in external B [$\mu(\bar{n}) = -\mu(n)$ from CPT]

Neutron-Antineutron transition probability

For $H = \begin{pmatrix} E+V & \alpha \\ \alpha & E-V \end{pmatrix}$ $\quad P_{n\to\bar{n}}(t) = \frac{\alpha^2}{\alpha^2+V^2} \times \sin^2\left[\frac{\sqrt{\alpha^2+V^2}}{\hbar}t\right]$

where V is the potential difference for neutron and anti-neutron.

Present limit (from SuperK data+Gal theory) on $\alpha \le 2\times 10^{-24}\, eV$

Contributions to V:

<Vmatter>~100 neV, proportional to density

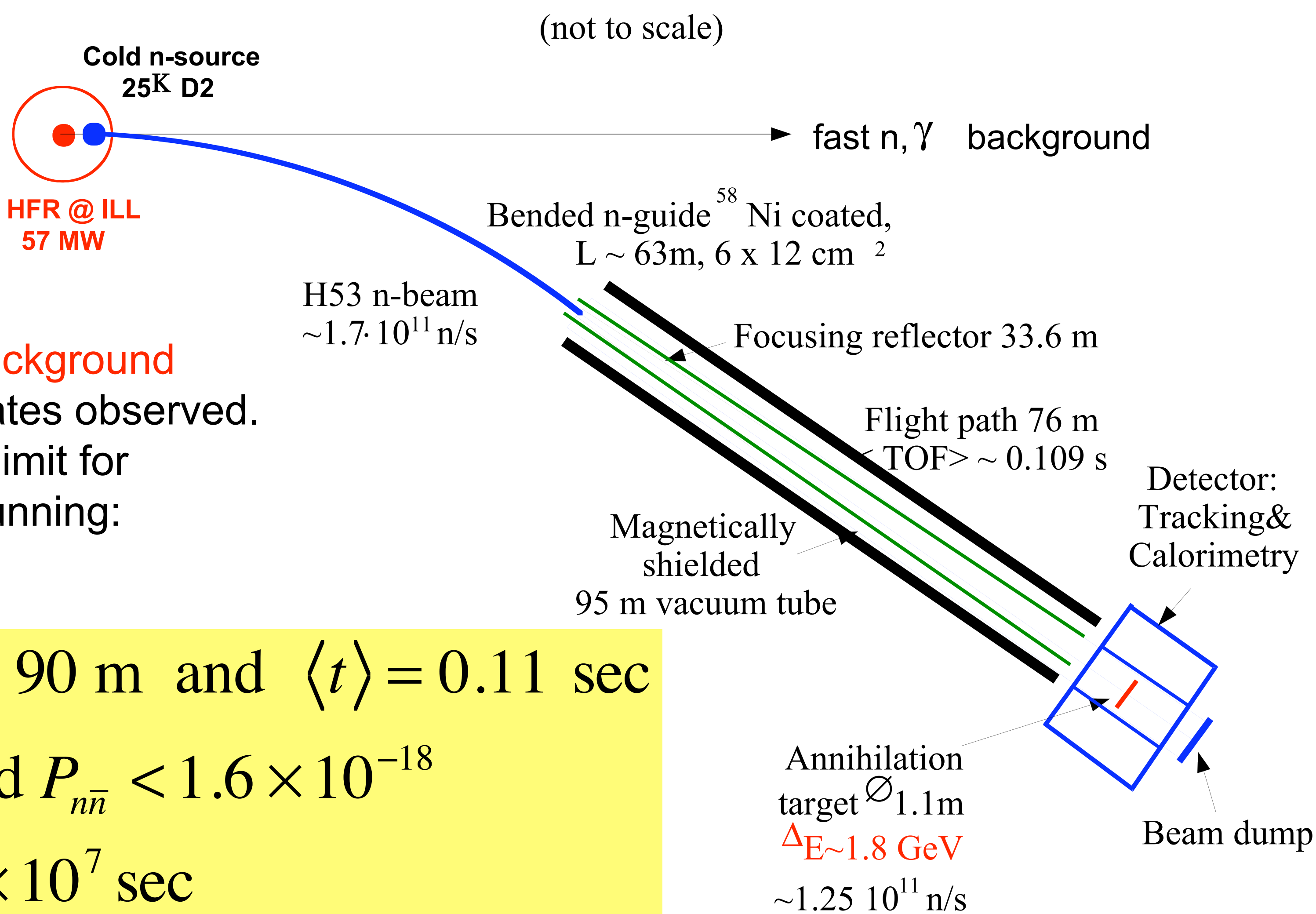
<Vmag>=μB, ~60 neV/Tesla; B~10nT-> Vmag~10^{-15} eV

<Vmatter> , <Vmag> both >>α

For $\left[\frac{\sqrt{\alpha^2+V^2}}{\hbar}t\right] << 1$ ("quasifree condition") $\quad P_{n\to\bar{n}} = \left(\frac{\alpha}{\hbar}\times t\right)^2 = \left(\frac{t}{\tau_{n\bar{n}}}\right)^2$

Figure of merit=NT^2 N=#neutrons, T="quasifree" observation time

N-Nbar search at ILL (Heidelberg-ILL-Padova-Pavia)



No GeV background
No candidates observed.
Measured limit for
a year of running:

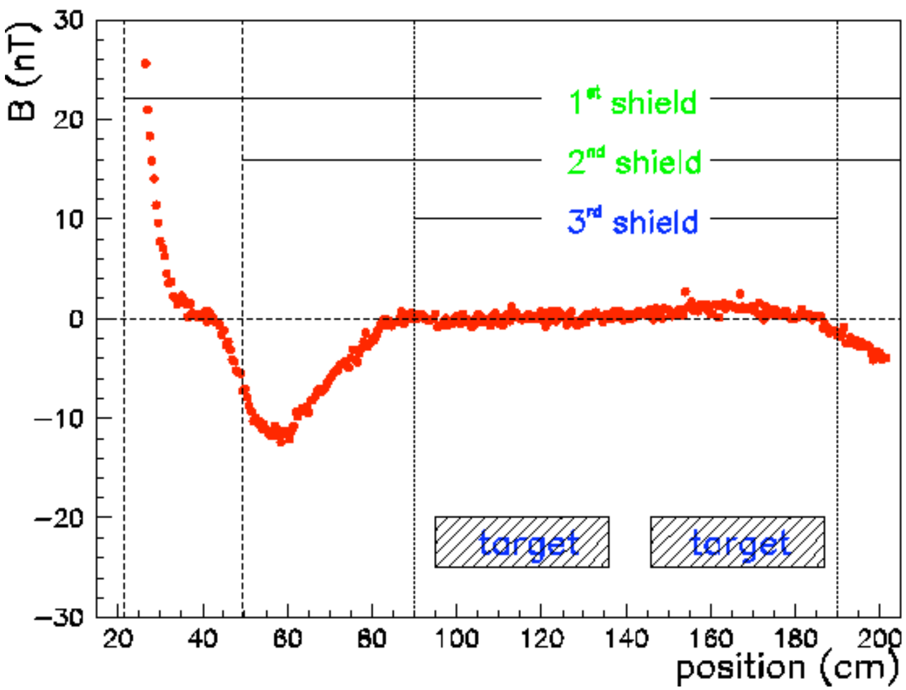
with L ~ 90 m and $\langle t \rangle = 0.11$ sec

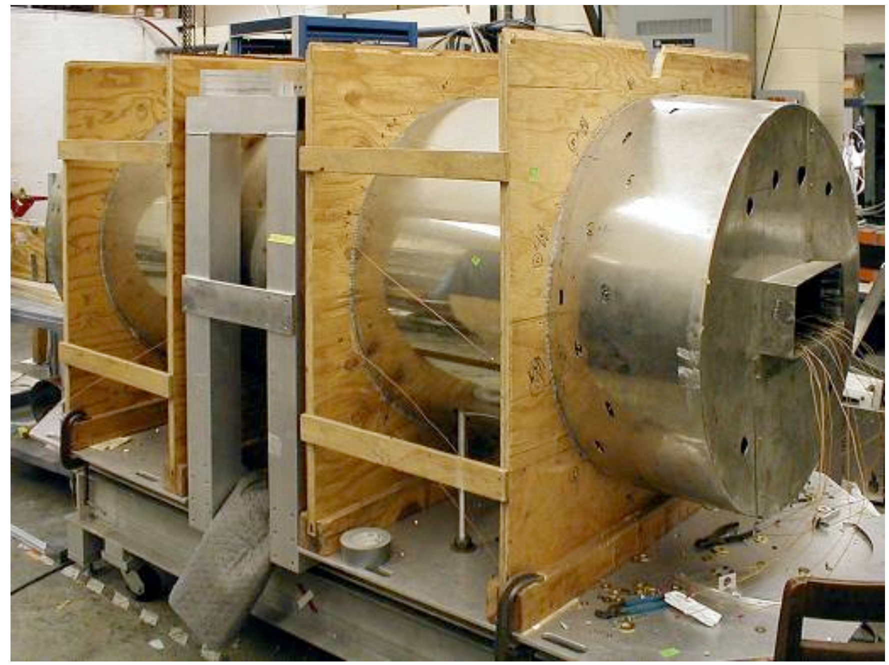
measured $P_{n\bar{n}} < 1.6 \times 10^{-18}$

$\tau > 8.6 \times 10^{7}$ sec

Baldo-Ceolin M. et al., Z. Phys. C63,409 (1994).

Magnetic Shielding Measurements for neutron spin rotation measurements at NIST





B~1 nT are routinely obtained in relatively small (few m^3) volumes with multiple shields

Large size of any n-nbar apparatus poses the challenge.

Large volume->cost minimization critical: price chaos from commodity speculators

Quasifree Condition: B Shielding

$\mu B t \ll \hbar$ ILL achieved |B|<10 nT over 1m diameter, 80 m beam,one layer 1mm shield in SS vacuum tank, 1% reduction in oscillation efficiency (Bitter et al, NIM A309, 521 (1991). For new experiment need |B|<~1 nT

Make shield long enough that residual axial field is uniform, then remove this with a solenoid. Beam kept 2m off the ground, away from disturbances (roads, iron, power cables, B fields) to achieve this Residual transverse fields trimmed and actively compensated

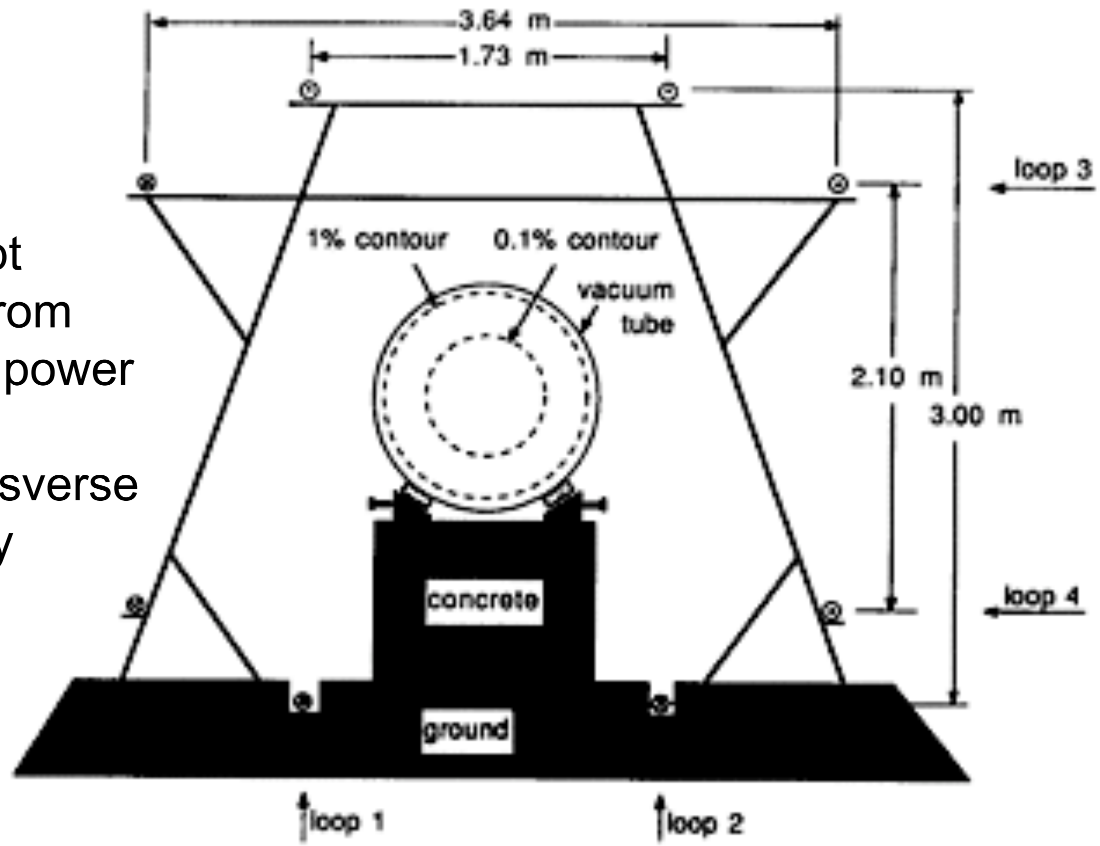
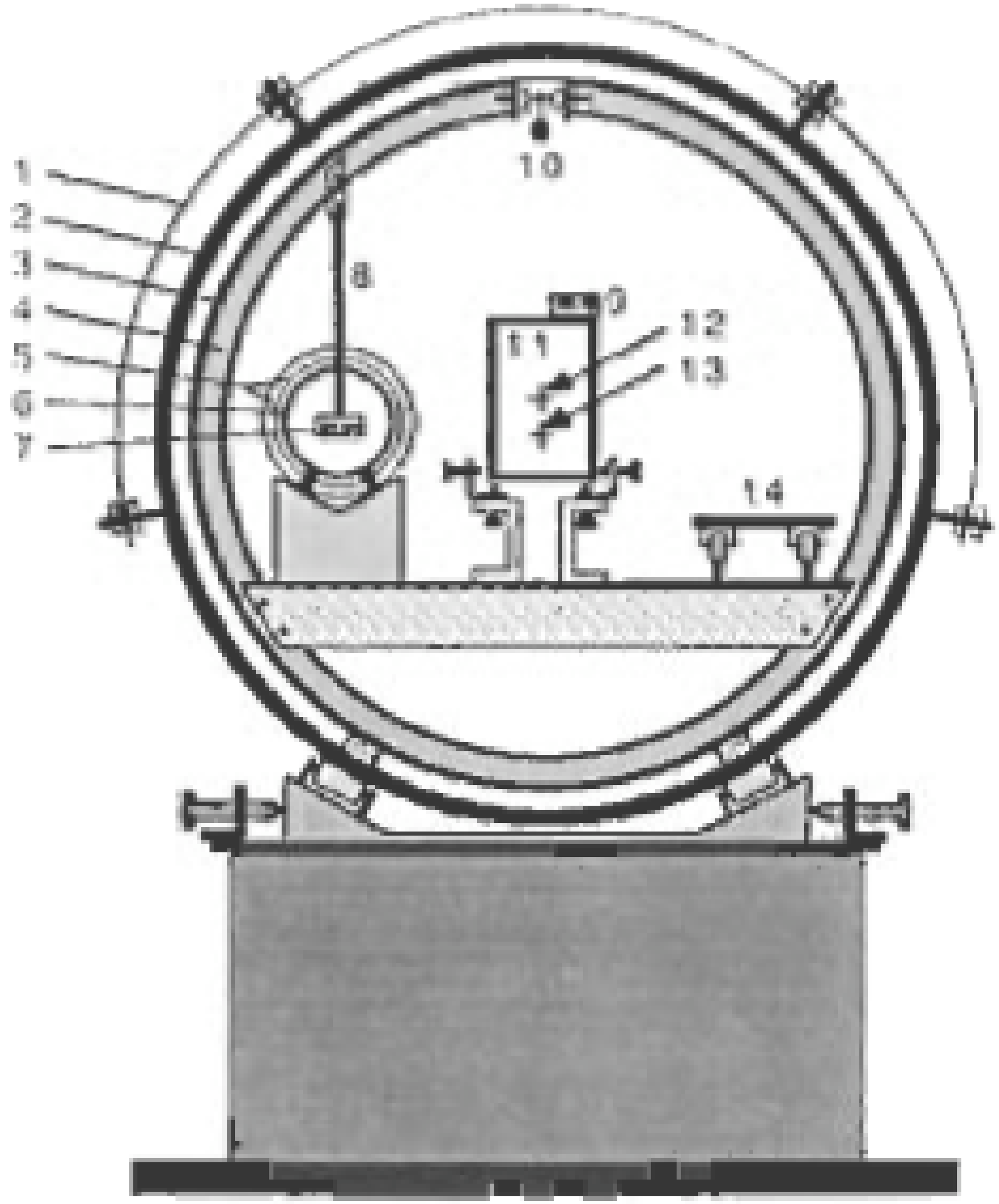


Fig. 10. The transverse field compensation system. Loops 1 and 2 are under 49 A current and compensate the horizontal field component; loops 3 and 4 are under 120 A current and compensate the vertical field component.

B Shielding Measurement At ILL

Magnetometer+ Zero-field chamber periodically transported along length of tube, measures axial field component, slightly off-axis

T. Bitter et al NIM A309, 521 (1991)



Quasifree Condition: Neutrons as the magnetometer

Performed by polarized neutrons from supermirror reflection+
use of neutron spin echo spectroscopy (U. Schmidt et al, NIM A320, 569 (1992).

For new experiment may need polarizers and analyzers with larger phase space acceptance to polarize and analyze beam

U. Schmidt et al. / Propagation of a neutron beam 571

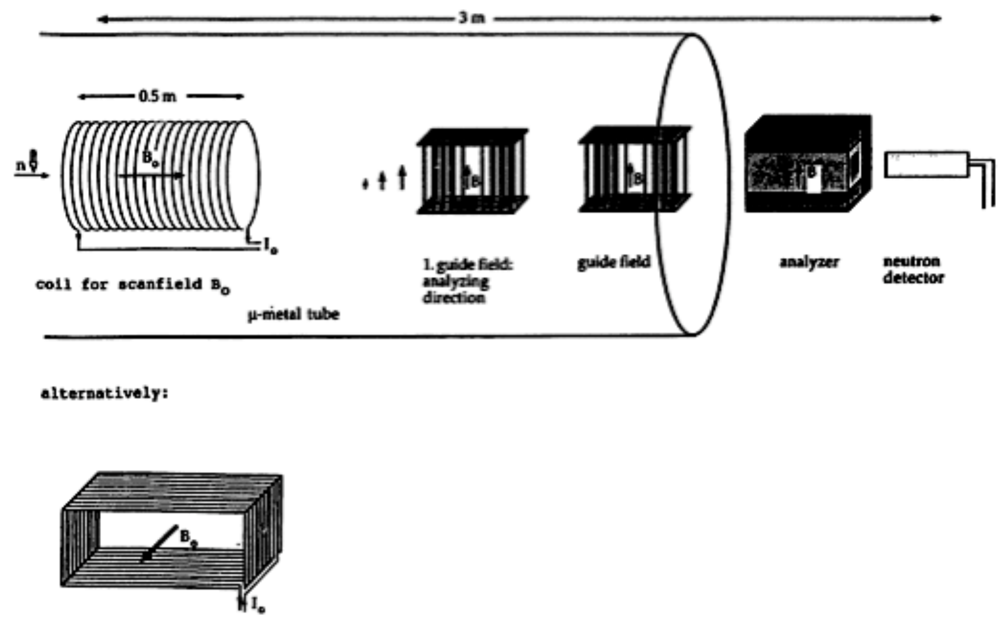


Fig. 3. Polarized neutron analyser equipment at the exit of the zero-field region, at 70 m distance to the polarizers of fig. 2.

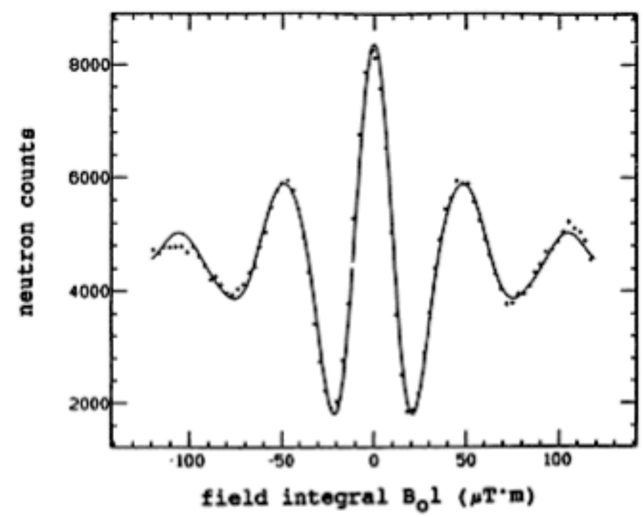
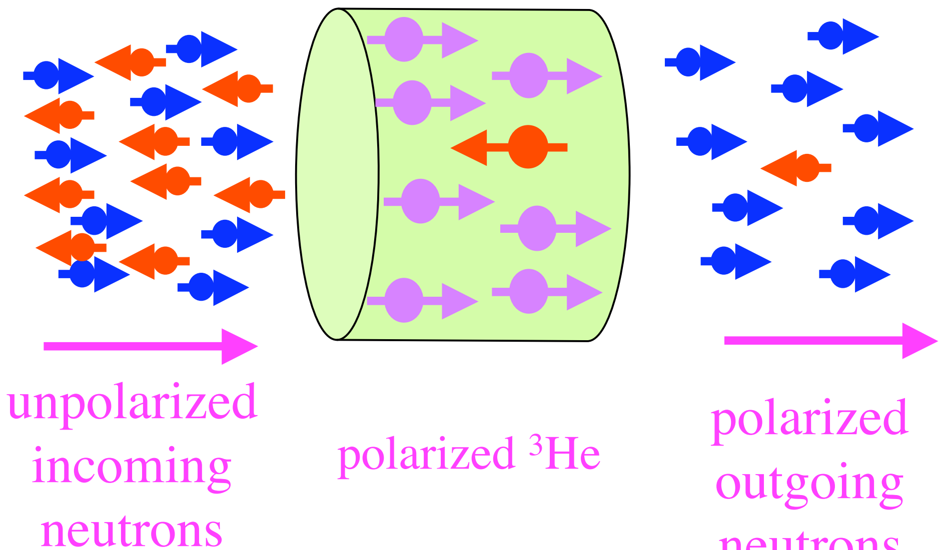
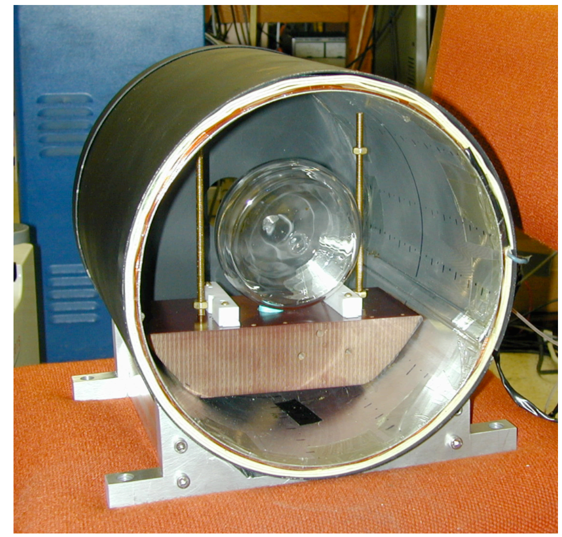


Fig. 4. Neutron-spin echo curve produced with the apparatus of figs. 2 and 3. The zero-offset of this curve measures the residual magnetic field along the magnetically shielded 70 m long neutron beam line to $\langle B_z \rangle = 4$ nT, via a neutron spin precession angle of $\phi = 2°$. The solid line is a fit to the theoretical lineshape.

POLARIZED ^{3}He for Neutron Polarimetry

Use neutrons as magnetometers. Polarize/analyze neutron beam using 3He





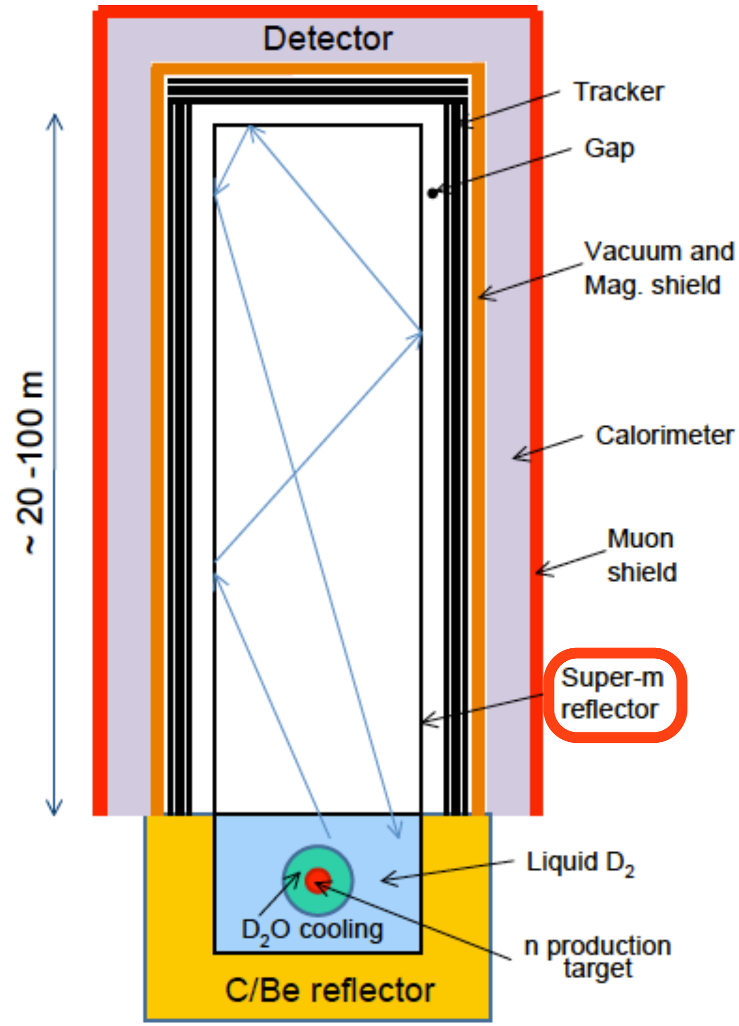
Polarized ^{3}He cell (11 cm diameter)

Large neutron phase space acceptance
Polarizer/analyzer pair can measure B using neutron spin rotation

NIST, Indiana, Hamilton, Wisconsin

DOE DEFG0203ER46093

n-nbar experiment using very cold neutrons: vertical option



Idea: to increase observation time and reduce gravitational aberrations in neutron focusing

As the observation time is increased, the B shielding requirements to meet the quasifree condition become more stringent

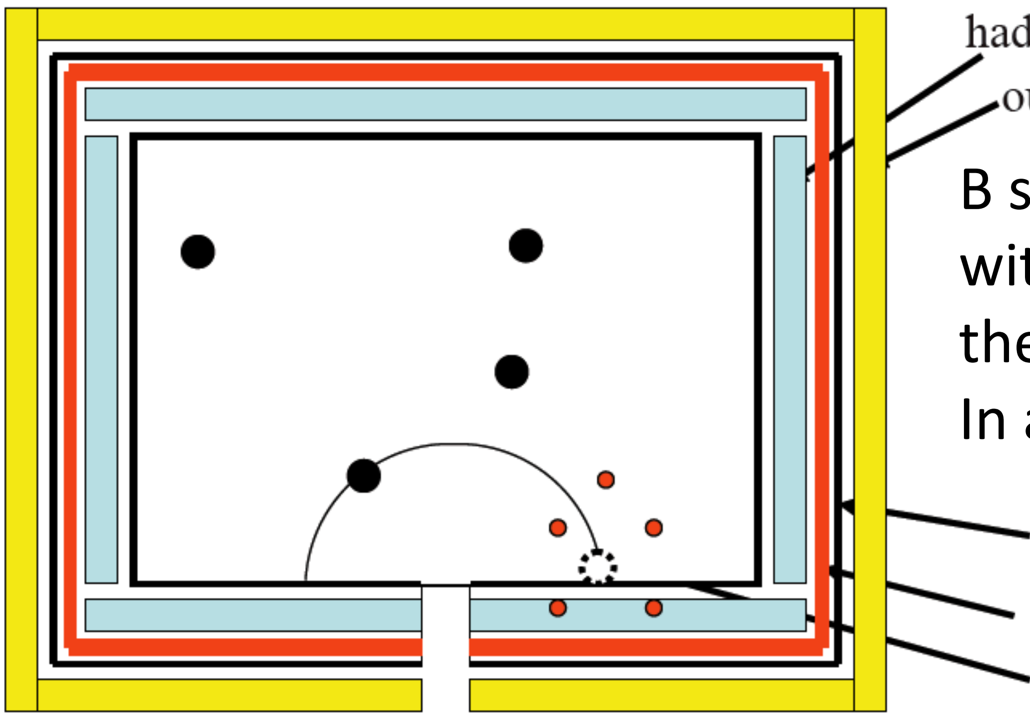
What is the tradeoff?

Magnetic Shielding At Petersburg Nuclear Physics Institute

Separated panel construction for segmented shield developed for Neutron EDM experiment

Photo courtesy A. Serebrov

NNbar with UCN



B shielding issue: how to deal with a different aspect ratio for the shielding geometry? Tfree In any case limited by gravity

Box filled with UCN gas…many samples/neutron
longer average flight times (~1/3 sec)
large neutron current required

Albert Young/NCSU

Required R&D

• Identification of scheme for suppression of external magnetic fields/field gradients in the presence of the μ-metal;

• Identification of an assembly, annealing, and demagnetization strategy;

• Measurement of the ambient magnetic field at the proposed location;

• Preliminary mechanical design of the shield;

• Analysis of the loss of sensitivity of the oscillation measurement to residual magnetic fields;

• Investigation of materials compatibility for the vacuum chamber.

•Verify maintenance of the field condition

•Investigate additional issues of shielding for vertical/UCN geometries